International Journal of Advancement in Engineering Technology, Management & Applied Science
Volume 3, Issue 6 June 2016 ISSN No: 2349-3224

Analysis of Blocking Probability in WDM Networks

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Abstract
Wavelength assignment algorithm is one of the important components of routing and wavelength assignments problem in WDM networks. This problem helps in the minimization of the blocking probability of the network. In this paper we have reviewed the wavelength assignment problem and discussed the history of this problem with a good literature review. Depending upon the literature and history of this problem we can conclude that the work can be done in this field for the minimization of the blocking probability of the network leading to the blocking free environment. The blocking probability can be calculated for the network with wavelength conversion and without wavelength conversion

Key words
Wavelength division multiplexing (WDM), blocking probability, Light paths, routing and wavelength assignment(RWA)

1. Introduction
In recent years, there has been a growing demand for networks able to transmit data at increasing speeds. Among the recent technologies used to increase the available link capacity is the Wavelength Division Multiplexing (*WDM*). WDM is a technology which multiplexes several optical signals onto a single optical fiber using different wavelengths, thus augmenting link capacity. In a WDM network, the connections between two nodes are established through channels of wavelengths that travel in a completely optical path, that is, a path without electro-optic conversion at the source node and optic-electro at the destination node. Such an optical path is referred as a light-path. A link may comprise several wavelengths, that is, λ_i for $0 \leq i \leq W$, where W represents the number of wavelengths available. The problem to find a path, *i.e.* a route, from a source to a destination node in a WDM network with a continuous and free wavelength along each link is non-trivial. Indeed, the above problem is known as the *Routing and Wavelength Assignment* (*RWA*) problem and was found to be NP-Complete [2]. With the aim to better use the *WDM* technology, a number of heuristics have been proposed in the literature to address the RWA problem [4] [5] [6] [11] [14].
In solving the RWA problem, it is usually assumed that the same λ_i is used along the selected path. A path p from a source s to a destination d is said to be continuous if the same λ_i is used through the path. Such constraint is called *wavelength continuity constraint*. Such constraint can be relaxed by using an optical converter at each node, but then cost becomes a major concern. One way to tackle with the RWA problem, without resorting to optical converters, is to split the RWA into two sub-problems: Routing problem (*R*) and Wavelength Assignment (*WA*) problem. The RWA problem is usually tackled in the following way: first, a routing algorithm is used to

International Journal of Advancement in Engineering Technology, Management & Applied Science

Volume 3, Issue 6 June 2016 ISSN No: 2349-3224

select the best route from the source to the destination node; next, the wavelength assignment algorithm attempts to obtain a free continuous wavelength along the selected path. The *blocking probability* can be defined as the probability of one request not to be attended by a free wavelength on the selected route. In this case, the request is blocked. Given a set of requests R={$r_1, r_2, ..., r_k$}, where each request r_i, $1 \le i \le k$ is formed by one source and destination pair (s_i, d_i), the RWA problem asks to find a path between (s_i, d_i), that has the same free wavelength λ_i in each link of the path. If this condition is not met the request is then blocked.

We have considered the blocking probability in the case where no wavelength conversion is taking place. The two constraints which are followed for the wavelength assignment and are:
1. Wavelength continuity constraint: a lightpath must use the same wavelength on all the links along the path from source to destination edge nodes.
2. Distinct wavelength constraint: all lightpaths using the same link must be allocated the distinct wavelengths
The call is said to be blocked when there is no free wavelength available for assignment in a link. The blocking probability is calculated using

$$P_{blocking} = \frac{N_{block}}{N_{gen}}$$

where $P_{blocking}$ is the blocking probability, N_{block} is the number of calls blocked and N_{gen} is the number of calls generated. The blocking probability can be calculated using the in-famous Erlang B formula

$$P_{blocking}(L,W) = \frac{\frac{L^W}{W!}}{\sum_{j=0}^{W} \frac{L^j}{j!}}$$

where $P_{blocking}(L,W)$ is the blocking probability, L is the load and W is the number of channels or wavelengths.

2. WDM Technology

There are two basic multiplexing mechanisms used in optical networks, Wavelength Division Multiplexing (*WDM*) and Optical Time-Division Multiplexing (OTDM) [1]. The former can be viewed as a way to multiplex several wavelengths into a single fiber while *OTDM* is a technique where several optical signals are combined, transmitted together, and separated again based on different arrival times. In this work we focus on *WDM* networks. The revolution in the transmission through fiber optics started in 1992 doubling the capacity at every six months reaching rates of 10 Tbps already in 2001. In a WDM networks, beams of laser are carried in

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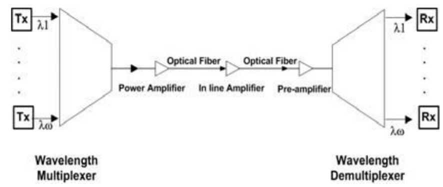
different wavelengths, which are used to implement end-to-end fixed connections. These fixed connections are called a *light-path*. The main restriction in relation to *light-path* is that different *light-paths* cannot share the same wavelength in the same optical fiber [3].



As can be verified in the Fig. 1, the WDM technology works as follows: at the transmitter side reside W independent transmitters. Each transmitter, denoted as Tx, is a source of light, such a laser, and is modulated independently as a stream of data. The output of each transmitter is an optical signal, named wavelength, denoted as λ_i, where $0 \leq i \leq W$. The optical signal of transmitters W are combined into a single optical signal by a multiplexer and transmitted over the optical fiber. At the other end, the optical signals are demultiplexed into W individual signals, which are then addressed to the appropriate receiver. The amplification is used after the wavelength multiplexing and before the wavelength demultiplexing [12].

A peer-to-peer WDM system provides W independent channels, all of them on the same fiber. As the WDM technology evolves, the number of wavelengths that can be transmitted at the same fiber increases as well. In other words, the link of a fiber can be increased without the need of adding new fibers, which is costly and time consuming. The addition or replacement of new fibers is considerably more expensive than the improvement of the necessary components.

3. Routing and Wavelength Assignment

In literature there are two methods to tackle the RWA problem. One of them is taking routing and wavelength assignment problem as a single problem and the other method is taking routing and wavelength assignment as two separate problems. In this paper the routing and wavelength assignment problem is considered as two separate problems, *Routing problem* and *Wavelength Assignment* problem. Several routing algorithms are proposed in the literature of which some are represented as below:

- *Fixed routing* [4]: The path for the source destination pair is calculated off-line using algorithms, say, Dijkstra algorithm
- *Fixed alternate routing* [4-5]: Instead of calculating one path for each pair, several alternate paths are calculated off-line in fixed alternate routing.
- *Adaptive routing* [6]: the paths are calculated online, depending on the networks state which reflects the resource usage.

There are many wavelength assignment algorithms some of them are mentioned as:

- *Random wavelength assignment* [Ra]: A wavelength is selected randomly from the available wavelengths.
- *First-fit assignment* [FF]: All the wavelengths are numbered. The wavelength with the lowest number is selected from the available wavelengths.

- *Least-Used* (LU): Selects the wavelength that is the least used in the network, thereby attempting to balance the load [11].
- *Most-Used*(MU): Is the opposite of LU in that it attempts to select the most used wavelength in the network [11] .

It was shown in [3] that the *Random* and *First-Fit* heuristics attain reasonable performance on a setting consisting of a single fiber. The advantage of *First-Fit* lies is the fact that it combines short communications and computation costs, since it is not necessary to have any global knowledge of the network .

The algorithms which are used for the simulation are first-fit algorithm and random algorithm. These algorithms can be illustrated as below:

1. *First-fit algorithm*: In this algorithm, first the wavelengths of the traffic matrix are sorted in the non-decreasing order. Then the algorithm steps through this sorted list for selecting candidate chains joined. Let u*ij* be the next highest wavelength element in the sorted list. Then, if both the nodes *i* and *j* are the end nodes of the two chains, the largest chain is formed by joining the two ends, otherwise the next highest element is considered. This process is carried on until all the chains are considered to form a single chain representing the linear topology.

2. *Random algorithm*: In this algorithm the wavelength is selected randomly from the available wavelengths. In this algorithm a number is generated randomly and wavelength is assigned to this random generated number. The algorithm for the random wavelength assignment is very simple and is limited to the generation on a random number but the algorithm for first-fit is a bit complex. The algorithm for the first-fit wavelength assignment can be illustrated by the given algorithm in fig 1.

Algorithm First-fit

begin
  sort elements of U in non-decreasing order;
  While (two or more chain exist) **do**
  begin
  let u*ij* be the next highest element in U;
  if (*i* and *j* are the end nodes of the two chains '*ij*' and '*jl*') **then**
    connect *i* and *j* to get the chain '*kl*';
  discard u*ij* ;
end;

Fig. 1 Algorithm First-fit

4.Simulation Results

In this section we will present the simulation results for random and First-fit wavelength Assignment algorithms In all the simulations the blocking probability of the network is compared depending upon the number of channels, Loads and the number of links. The number of wavelengths on all the links is kept constant.

The simulation is carried out on MATLAB 7.2 of Mathworks. In the first case we have fixed the values of the number of channels C=11, number of links= 10 and load (in Erlangs) is varied. The results are shown in fig 2-11.

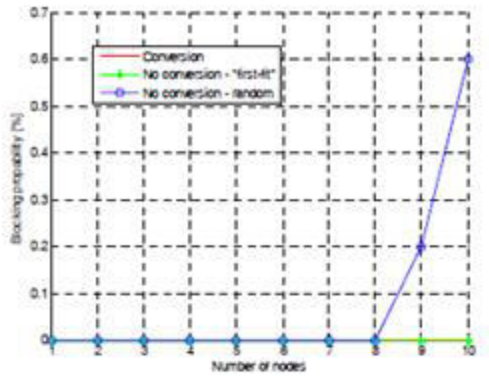


Fig. 2 Blocking Probability of 10 nodes for load 1 Erlang per link

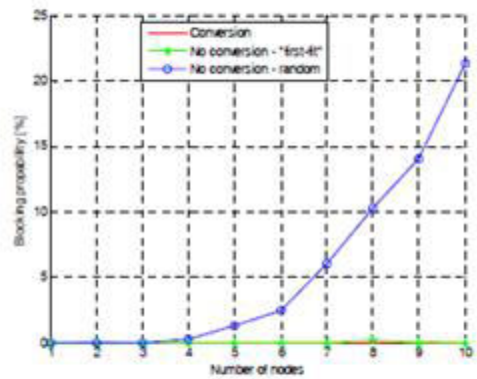


Fig. 3 Blocking Probability of 10 nodes for load 2 Erlangs per link

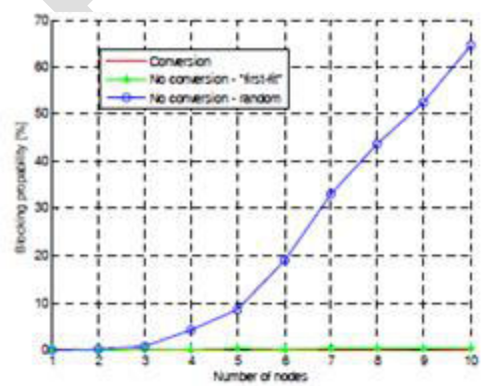


Fig. 4 Blocking Probability of 10 nodes for load 3 Erlangs per link

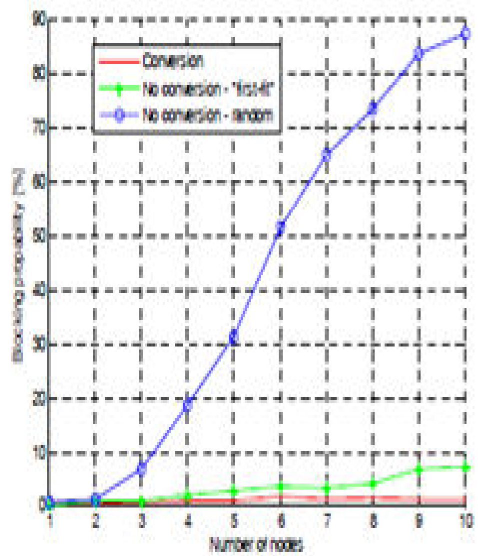


Fig. 5 Blocking Probability of 10 nodes for load 4 Erlangs per link

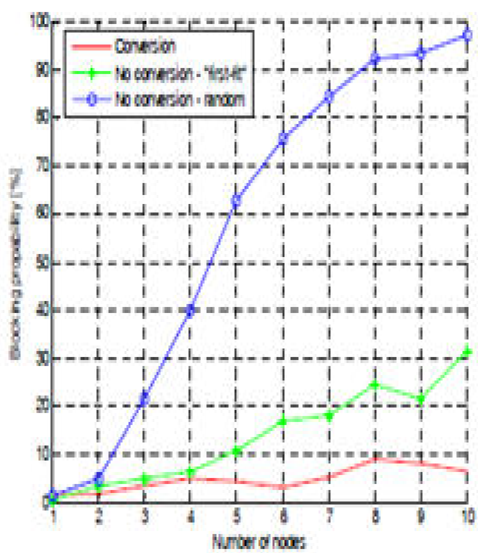


Fig. 6 Blocking Probability of 10 nodes for load 5 Erlangs per link

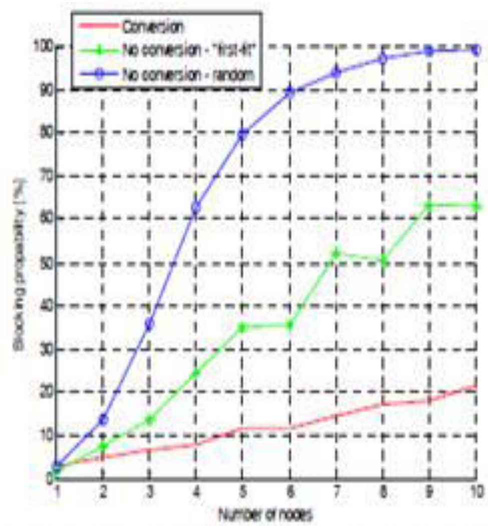


Fig. 7 Blocking Probability of 10 nodes for load 6 Erlangs per link

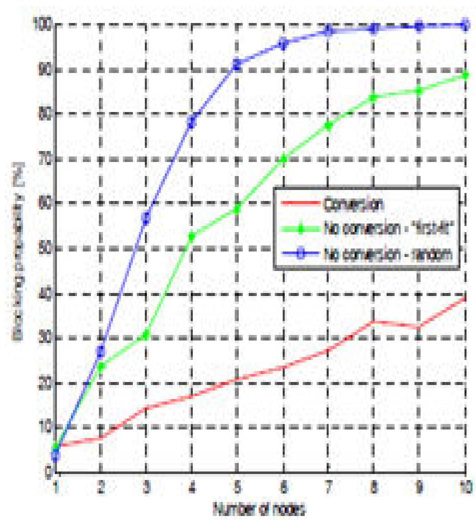


Fig. 8 Blocking Probability of 10 nodes for load 7 Erlangs per link

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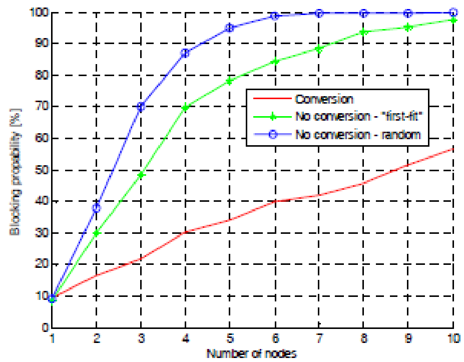

Fig. 9 Blocking Probability of 10 nodes for load 8 Erlangs per link

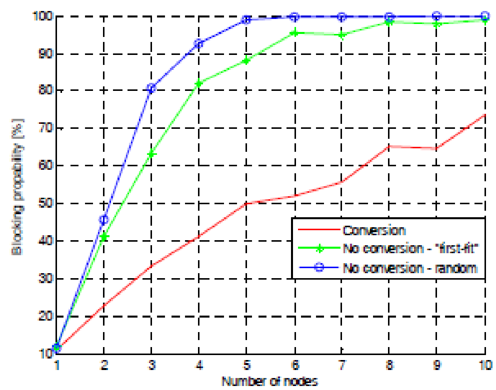

Fig. 10 Blocking Probability of 10 nodes for load 9 Erlangs per link

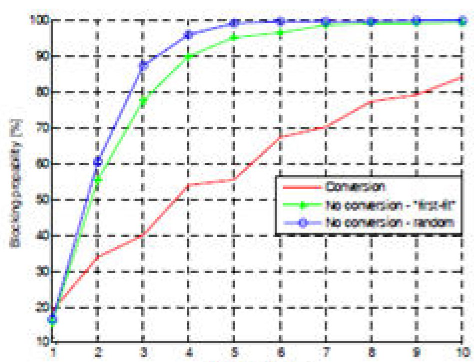

Fig. 11 Blocking Probability of 10 nodes for load 10 Erlangs per link

The above shown simulation results shows how the blocking probability (%) increases with the number of nodes. The blocking probability in case of random algorithm is always greater than that of First-fit wavelength assignment algorithm. Fig. 2 – fig.11 shows that the blocking probability of 10 nodes both with wavelength conversion and with no conversion, for load

ranging from 1 Erlang to 10 Erlang per link. The blocking probability is minimum in case of wavelength conversion, whereas in case of no conversion the first-fit algorithm has better results as compared to that of random wavelength assignment algorithms.

4. Conclusion

We have analyzed the response of blocking probability of a network having 10 nodes and for varying load. As the load per link (in Erlangs) increases, the blocking probability increases. The results shows that the response of first-fit is better than random algorithm whereas the response of wavelength conversion is much better than without conversion i.e. with first-fit and random algorithm

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